Shallow-Water Propagation

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LONG-TERM GOALS

Develop propagation models and related methods for complex shallow-water environments, determine their capabilities and accuracy, and apply them for simulating and understanding experimental data.

OBJECTIVES

(A) Treat propagation accurately from narrowband and broadband sources over elastic and poro-elastic sediments, and incorporate influences of realistic bathymetry and geoacoustic layering.

(B) Determine field statistics efficiently from stochastic propagation models, quantify effects of random environmental and experimental variability, and analyze data using model computations.

APPROACH

(A) Develop high accuracy PE techniques for applications to shallow-water sediments that are anisotropic and dispersive. Treat range dependence and layering by energy conservation and mapping methods. Benchmark results using independent computational procedures.

(B) Construct stochastic ensembles for geoacoustic and ocean variability using data and efficient model representations. Perform field calculations with PE, normal mode, and perturbation methods. Test model predictions using independent data sets.

Principal collaborators are: Rensselaer graduate students and recent graduates; Dr. Michael Collins (NRL) for model development; and Dr. William Carey (BU), Dr. Mohsen Badiey (Delaware), and Dr. James Lynch (WHOI) for modeling and analysis of experimental data.

WORK COMPLETED

(A) Our new PE formulation for elastic sediments [1] demonstrated its capabilities for accurate and efficient propagation calculations in layered environments with Rayleigh, Scholte, or Stoneley interface waves. The method has strong numerical stability that allows treatment of situations with seismic sources, sediment anisotropy, and relatively low shear speeds [2]. Energy conservation techniques permit accurate determination of propagation in range-dependent elastic sediments [3], including those with undulating interfaces and interfacial waves. A new extension handles problems with both complex layering and steep slopes [4], such as coastal shelves and beaches, provided the rate

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14. ABSTRACT
Develop propagation models and related methods for complex shallow-water environments, determine their capabilities and accuracy, and apply them for simulating and understanding experimental data.

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of slope change is small. We found that broadband signals which penetrate elastic sediments can develop significant dispersive effects as a result of frequency-dependent attenuation [5]. We performed new computations [6] with our PE formulation for poro-elastic sediments that have transversely isotropic (TI) geoacoustic properties. The directional dependence of wave speeds in layered TI elastic sediments can now be obtained from wave number spectra [7] using multiple frequencies and a coordinate rotation method. Improved efficiency for PE calculations is feasible [8] by combining key features of two previous split-step algorithms.

(B) Propagation modeling of broadband data from one track of the SWARM95 experiment shows that observed integrated energy variations arise from coupling between dominant acoustic modes and internal solitons [9]. However, variations measured over the same time period across a second track [10] require a different energy transfer mechanism for their explanation. The importance of geoacoustic layer structure was confirmed for these tracks [11], and correlations were found between observed thermal and intensity statistics. Incorporating upper sediment layer attenuation with nonlinear frequency dependence enables the modeling of principal features in four independent narrowband and broadband data sets from one track of the ACT III experiment [12]. Comparisons between propagation computations and measurements along a nearby track [13] provide additional validation of our oceanic and geoacoustic models. New perturbation calculations permit estimates of coherence degradation [14] arising from environmental variability that is not necessarily horizontally isotropic or homogeneous. Both normal mode and PE computations show [15] that intensity fluctuations in the AGS92 experiment result from the substantial sediment sound speed variability in that area. Broadband intensity fluctuations observed in this experiment are significantly influenced by the nonlinear frequency dependence of sediment attenuation [16].

RESULTS (from two selected investigations)

- One major challenge for shallow-water propagation predictions is accurate treatment of acoustic interaction with layered elastic sediments in which the layer interfaces as well as the bathymetry are range dependent. When sufficient data on sediment morphology is available, interface range variations are invariably observed. Our PE formulation for range-independent layered elastic sediments [1] achieved advances over previous approaches by satisfying all physical conditions at interfaces while maintaining robust computational stability. We have extended this method [3] to treat range-dependent interfaces, which are shown to have important effects on propagation characteristics. For example, the top contour plot in **Figure 1** illustrates a three-layered sediment having a dome formation in the lowest layer that blocks propagation in the middle layer, which regains some of the acoustic energy beyond the dome. The lower contour plot shows a two-layer sediment with a strong density contrast that permits a Stoneley wave to propagate along the undulating interface. We conclude that our method provides a new and unique capability for determining geoacoustic influences on shallow-water predictions.

- Several recent experiments have confirmed that large amplitude internal solitons, which occur in many shallow water environments, significantly affect acoustic variability. Their influence on broadband signals is a fundamental research issue whose resolution also has consequences for systems applications. In developing simulations for two tracks in the SWARM95 experiment, we found [9] that modeling the behavior of received signal-integrated energy can determine the quantitative effects of solitons. One illustration shows depth-averaged data at the NRL VLA

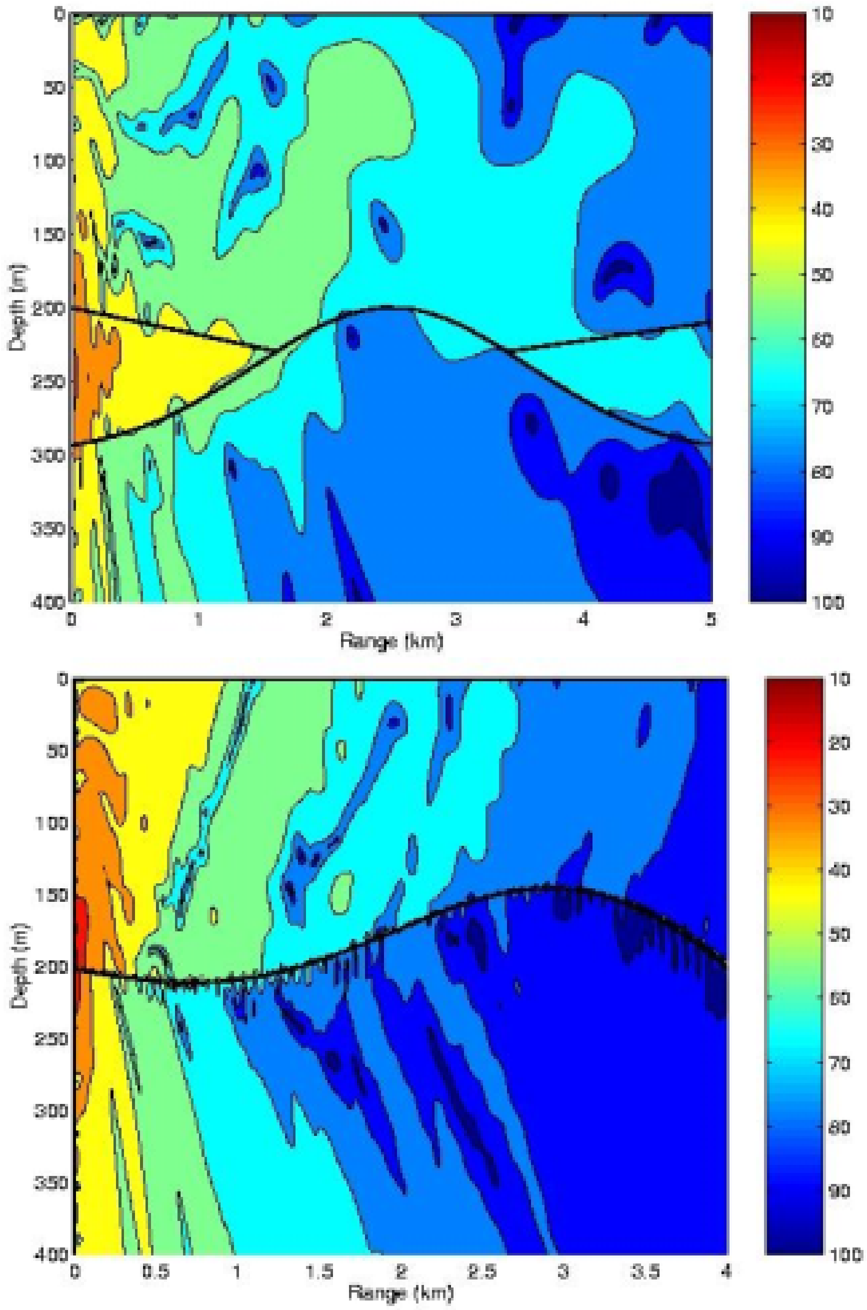

Figure 1. Range dependence of layered elastic sediments produces propagation effects that are treated accurately and efficiently by our new PE formulation. Transmission loss contours (to 400 m depth and up to 5 km range) for source frequency 25 Hz are shown for two layered sediments. Top: Three-layer elastic sediment has a middle layer with the lowest sound speeds and a source at 250 m. A dome-like protrusion of the lower interface eliminates the middle layer for about 2 km along the propagation range. The dome forces most of the acoustic energy into the upper layer. Beyond the dome some energy re-enters the middle layer and propagates within this waveguide. Bottom: Two-layer sediment has the same shear speeds and a strong density contrast, which allows the existence of a Stoneley wave. The interface undulates with a quasi-wavelength of about 4 km. A source at 205 m excites the Stoneley wave, which follows the interface variations as it propagates and decays with depth into both layers.

[dashed blue curves in **Figure 2**] from a source 18 km away, compared with PE simulations [solid red] that account for a train of eight solitons. Both observations and computations show similar oscillations with time that arise from the propagating solitons, in filtered bands centered at 32 Hz [top] and 64 Hz [middle], and over the full source spectrum [bottom, plotted about mean energy]. The physical mechanism causing the variations is coupling between wavenumbers from soliton energy spectrum peaks and from differences of dominant acoustic modes. We conclude that this mechanism, known previously to operate for cw sources and high frequencies, can also occur for broadband sources at low frequencies.

IMPACT/APPLICATIONS

New or improved capabilities for handling shallow-water sediment physical properties, including elasticity, porosity, anisotropy, and dispersion, will be available for propagation predictions. The geometrical sediment variability, such as range-dependent bathymetry and layer interfaces, will be accurately treated for predictions. Efficient specification of intensity and coherence statistics that result from environmental fluctuations and experimental variability will be feasible. Data analyses and comparisons will allow determination of the significance of physical mechanisms including attenuation frequency dependence and vertical and horizontal coupling due to internal waves, both in experimental results and for applications.

TRANSITIONS

Results from modeling and data analyses of several experiments (HCE, AGS, ACT, SWARM) are directed partly toward improving sonar systems and predictions in shallow water. Implementations of new propagation models and data representation techniques have been distributed to university and laboratory research groups.

RELATED PROJECTS

- Additional research with Dr. Michael Collins includes derivation and implementation of a PE model for internal gravity waves that treats both strong horizontal flows and wide-angle propagation effects [17].

- Current research with Dr. William Carey and Dr. James Lynch focuses on signal gain and coherence modeling in the Strait of Korea and also examines the predictability of range-averaged broadband propagation properties [18].

- Further research with Dr. Mohsen Badiey demonstrates how heterogeneous sediments with complex stratigraphy that are known to occur in coastal waters can cause azimuthally coupled propagation [19].

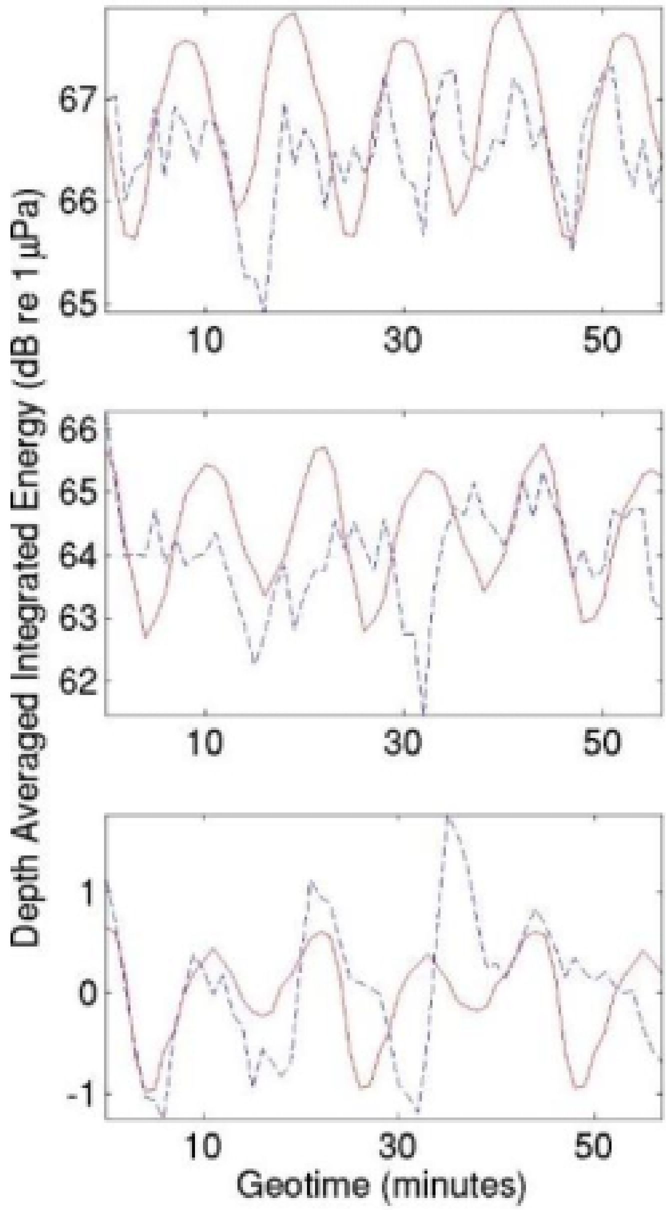

Figure 2

Figure 2. The quantitative influence of internal solitons on time variability of received broadband signals can be found from PE computations. In the SWARM95 experiment, signals from an air gun source on the R/V Cape Hatteras were received at the NRL VLA. Curves show depth-averaged signal-integrated energy from observations [blue dashed] and computations [red solid] over about sixty minutes. Top: Energy in a 10-Hz band centered at 32 Hz. The simulations show oscillations of about 12 min period and 2 dB amplitude. The data has similar and somewhat noisier behavior. Middle: Same, except with frequency band centered at 64 Hz [overall band energy is lower by about 2.5 dB]. The oscillation amplitudes extend up to about 3 dB. Bottom: Same, except with bands 10-250 Hz [data] and 10-150 Hz [computations], with curves plotted about mean energy [total amplitude variation 2 to 3 dB]. The variability arises from coupling between wavenumbers from soliton energy spectrum peaks and dominant acoustic modes.

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PUBLICATIONS

- Published: [2], [12], [15], [17]

- Submitted: [6], [16], [18], [19]